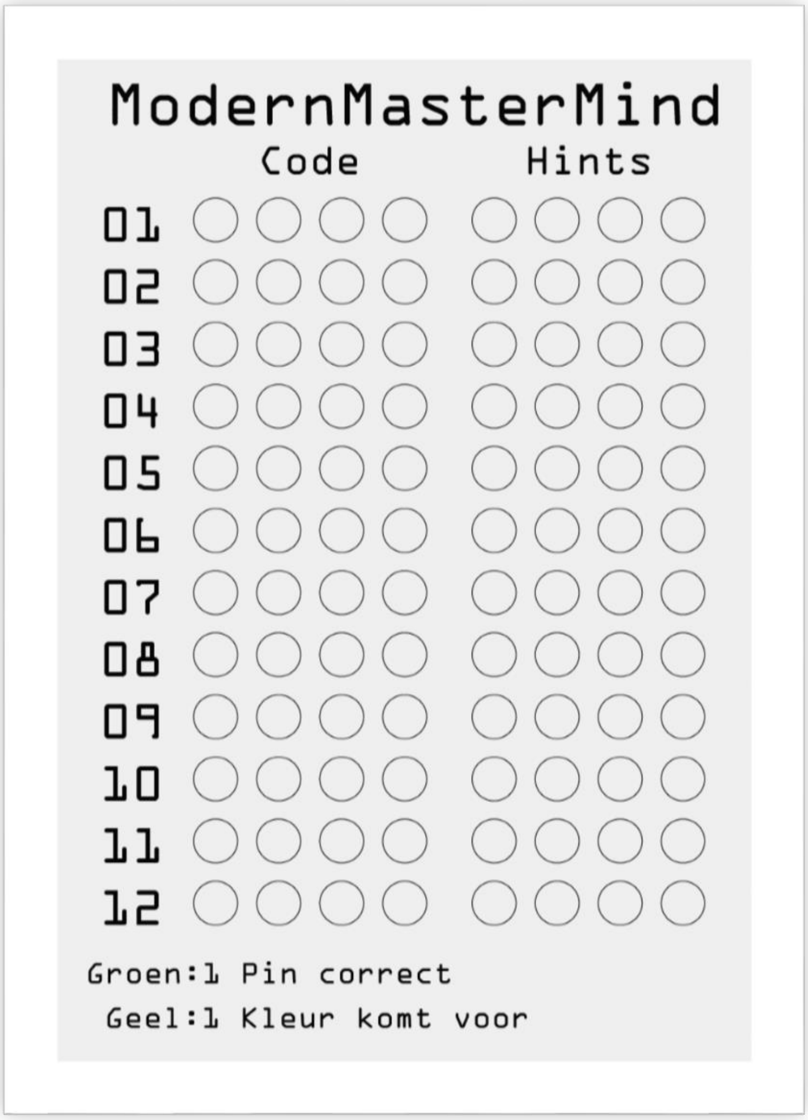


ModernMasterMind

PROJECT I – ICT-ELEKTRONICA

Dries Kennes | Project I | 2014-2015

1 Voorwoord

Ik ben Dries Kennes, student ICT-Elektronica Fase 1 aan Thomas More Mechelen op Campus De Nayer. Mijn voornaamste interesses zijn elektronica en alles wat te enigszins programmeren valt. Online ga ik door het leven als Dries007, een enthousiaste Java programmeur die zich in zijn vrije tijd vooral bezighoud met het maken van build-to-order Minecraft mods.

Tijdens de kerstvakantie ben ik op zoek gegaan naar projectonderwerpen. Vorig jaar (6e jaar middelbaar) wilden wij tijdens de lessen elektronica met een Arduino en een LED matrix spelletjes maken. Helaas was het juiste materiaal niet tijdig beschikbaar. Daarom heb ik er dit jaar voor gekozen om één van die spellen uit te werken. Het werd Mastermind omdat dit een uitdaging leek, onder andere dankzij de vereiste om kleuren te kunnen weergeven.

Mijn contacteren kan via email, dries.kennes@student.thomasmore.be, of via mijn website, dries007.net.

Ten slotte wil ik Marc Roggemans bedanken voor het uitlenen van materiaal en Jurre De Weerdt voor het helpen met solderen van enkele SMD onderdelen.

2 Inhoud

3 Hardware

3.1 RIOT

RIOT staat voor Remote Internet Operated Terminal, en is een ontwerp van M. Roggemans en D. Pauwels. RIOT werd ontworpen als educatief platform in 2002, maar is eigenlijk nooit gebruikt. Meneer Roggemans heeft tijdens de lessen interfacetechnieken dit platform wel aangehaald, en zo kreeg ik interesse om dit te gebruiken. Ik kreeg toegang tot de bordjes na de examens na de kerstvakantie, zodat ik hiermee kon experimenteren, en zien of ze bruikbaar zouden zijn als basis voor mijn project. Het gebruiken van een 10+ jaar oud platform zorgt voor een aantal hindernissen, meer hierover in het hoofdstuk *Software*.

Meer informatie over RIOT is beschikbaar in op Telescript[1].

3.2 Het basisprincipe

Het basisprincipe van RIOT (en dus ook mijn project) is dat 2 controllers met elkaar communiceren via een gedeeld geheugen (een Dual Port RAM, voortaan DP-RAM). Dit geheugen heeft een aantal 'gewone' adressen die vrij kunnen worden gebruikt, en 2 interrupt adressen. De interrupt adressen worden gebruikt om, zoals de naam al doet raden, van de ene controller naar de andere een interrupt te genereren. De controllers zijn een Beck SC12 en een AVR ATMega128A.

De reden voor het gebruiken van een dergelijk systeem is in dit geval de hoeveelheid IO verhogen. De SC12 heeft namelijk een zeer beperkte hoeveelheid IO, die vooral op pinnen zit die al door andere functies in gebruikt zijn (bijvoorbeeld UART of I^{2}C). De SC12 heeft echter wel een gemultiplexte 8 bit data/adres bus, waarmee een extern geheugen van 256 bytes kan worden aangesproken. Door 2 IO pinnen te gebruiken als adres lijnen 8 en 9 kan het aanspreekbare geheugen worden uitgebreid tot 1kb (4 pages van 256 bytes).

Aangezien een Mastermind spelbord 12 rijen heeft van 8 gekleurde (RGB) pionnen, dit zijn in totaal dus 12 x 8 x 3 = 288 bytes is dit trucje geen overbodige luxe. Als men dan nog op een eenvoudige manier een LCD wil aansturen (20 karakters x 4 lijnen) heeft men nog eens 80 bytes nodig. Uiteindelijk zou 512 bytes genoeg zijn geweest, maar een DP-RAM chip met 1kb is commercieel beschikbaar, 512 bytes niet.

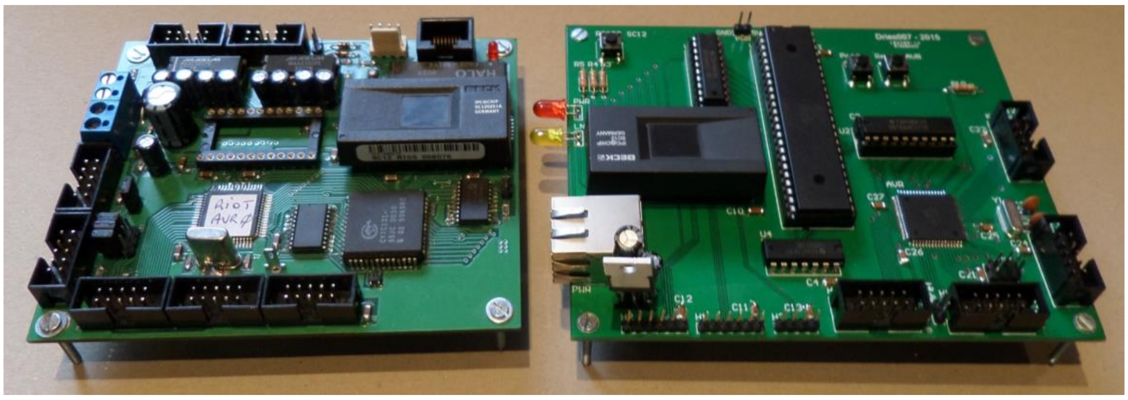
Aangezien de adres- en databus van beide controllers gemultiplext zijn, is het nodig om een adres latch te gebruiken. Ik gebruik 74AHC573 chips aangezien die aan de timingsspecificaties van de ATMega128A voldoen.

Voor de LEDs gebruik ik WS2812 LEDs. Deze LEDs zijn ideaal voor dit project omdat ze, ongeacht de hoeveelheid LEDs, maar 1 pin op een (relatief snelle) controller nodig hebben. Ze worden namelijk allemaal in serie geschakeld. De werking van het protocol word uitgelegd in het hoofdstuk '*Het WS2812 protocol*' .

[1] ftp://193.191.150.44/pub/CD-Microcontrollers/RIOT/

3.3 De PCBs

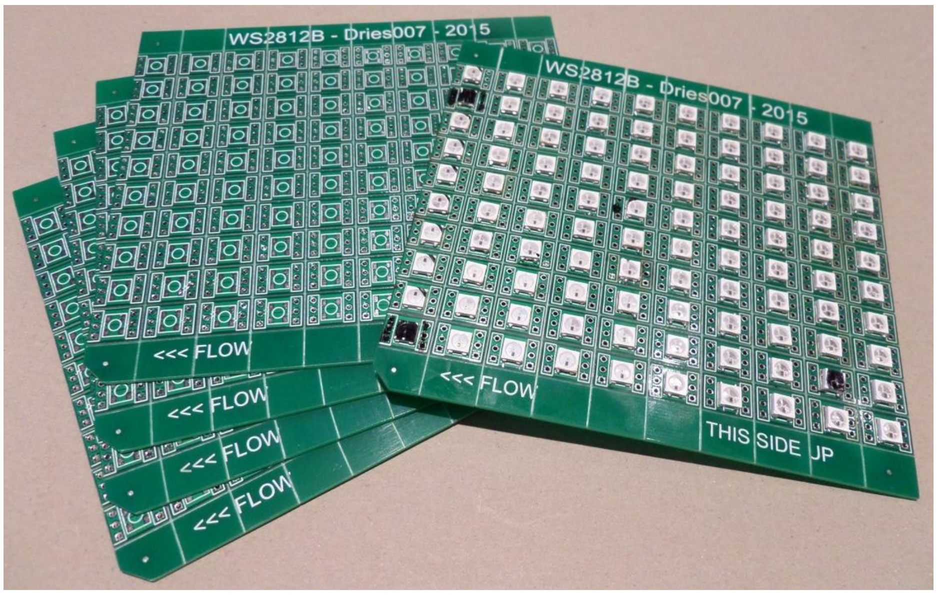
Op mijn versie van het bord zijn onnodige onderdelen weggelaten. Onder andere de UART naar RS232, de Real Time Clock en het voedingscircuit moesten er aan geloven.


Figuur 3.1 RIOT links, Eigen PCB rechts

De PCBs zijn getekend met Altium. Het main bord en de LCD breakout zijn besteld bij Seedstudio, het LED panel bij multi-cb. De bestukking was manueel. De volgende fouten heb ik achteraf (tijdens het testen of solderen) ontdekt:

- De databus van het DP-RAM naar de AVR is in omgekeerde volgorde (de bits zitten omgekeerd).
- De WS2812 LEDs passen maar net op de getekende footprint, wat wil zeggen dat ze bijna onmogelijk met een gewone soldeerbout soldeerbaar zijn. Gelukkig heb ik op school hulp gekregen, en mocht ik een warme lucht soldeerstation gebruiken.

Het volledige schema en de layout van de PCBs is beschikbaar in de bijlage *PCB Schema's & Layout*.



Figuur 3.2 Het LED panel

4 Software

4.1 De memory map

Dit is de verdeling van het DP-RAM. De 2 interrupt adressen liggen vast, namelijk `0x3FE` en `0x3FF`.

Adres	Functie
`0x000 -> 0x1FE`	RGB data voor maximaal 170 LEDs
`0x1FF`	Aantal LEDs
`0x200 -> 0x250`	LCD buffer (80 karakters)
`0x251`	LCD commando
`0x252`	LEDs dim
`0x253`	Laatst ingedrukte toets op keypad
`0x245 -> 0x3FD`	Vrij geheugen
`0x3FE`	Interrupt SC12 -> AVR
`0x3FF`	Interrupt AVR -> SC12

Tabel 4.1 De geheugenallocatie van het DP-RAM

Het interrupt adres `0x3FE` word gebruikt als een commando register van SC12 -> AVR.

Waarde	Functie
`0x00`	Geen functie
`0x01`	Update LEDs
`0x02`	Print LCD karakter buffer (tot max of `0x00`)
`0x03`	Stuur LCD instructie
`0x04`	Stuur clear instructie en print LCD karakter buffer
`0x05`	Zet LCD cursor positie op LCD commando
`0x06`	LCD backlight aan
`0x07`	LCD backlight uit

Tabel 4.2 De commando's van de SC12 naar de AVR

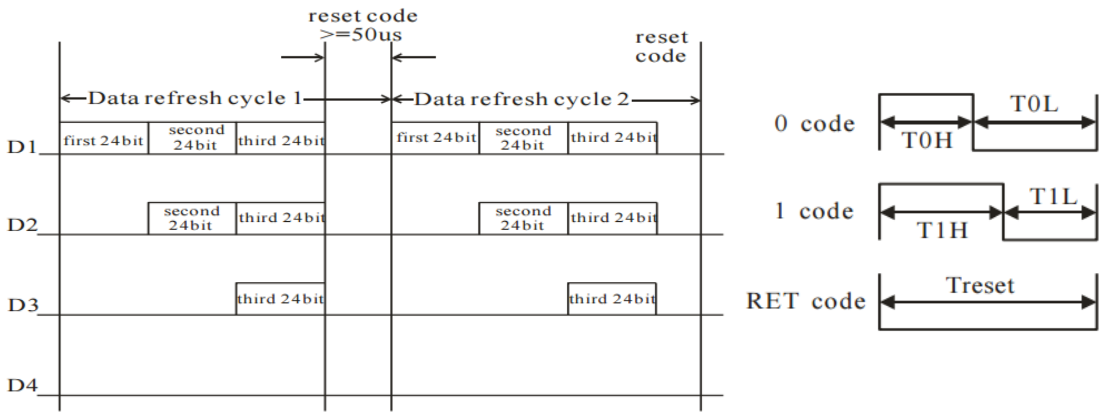
Het interrupt adres `0x3FF` word gebruikt als een commando register van AVR -> SC12.

Waarde	Functie
`0x00`	Geen functie
`0x01`	Keypress

Tabel 4.3 De commando's van de SC12 naar de AVR

4.2 Het WS2812 protocol

De WS2812 LEDs werken als een lange serie schakeling, waarbij elke led de eerste 24 bits gebruikt om zijn kleur in te stellen. De andere bits worden doorgegeven, zie *Figuur 4.1*. De volgorde van de bits is niet RGB, maar GRB, met hoogste bit eerst.



Figuur 4.1 LED cascading & timing diagram

Code	Betekenis	Tijd	Min	Typ	Max
`T0H`	0 code - high voltage time	0,35 µs ±150 ns	200 ns	350 ns	500 ns
`T1H`	1 code - high voltage time	0,70 µs ±150 ns	550 ns	700 ns	850 ns
`T0L`	0 code - low voltage time	0,80 µs ±150 ns	650 ns	800 ns	950 ns
`T1L`	1 code - low voltage time	0,60 µs ±150 ns	450 ns	600 ns	750 ns
`Reset`	low voltage time	> 50µs	50 µs		
`TH+TL`	Cyclus time	1,25µs ±600ns	660 ns	1250 ns	1850 ns

Tabel 4.4 De timing tabel uit de datasheet, met genormaliseerde waarden

De software driver die vaak voor de ze LEDs word gebruikt (Adafruit NeoPixel Library[2]) is ingewikkeld, geschreven in C++ en geschikt voor zowel 8, 12 als 16 MHz Arduino's. Na verder zoeken vond ik een aantal interessante artikels[3] die de timing van de LEDs analyseren.

Uit hun analyse blijkt dat de timing eigenlijk niet zo restrictief is als lijkt uit de datasheet. De enige kritieke tijd blijkt `T0H` te zijn, en die is net haalbaar op 4MHz (500ns * 4MHz = 2 klokcycli). Alle andere timing restricties zijn langer, en kunnen dus met nops worden ingevuld.

Uiteindelijk heb ik ervoor gekozen een aangepaste versie van de *light_ws2812 library*[4] te gebruiken. Dit is de code die word beschreven in een van de artikels. Ze is simpel en eenvoudig te begrijpen.

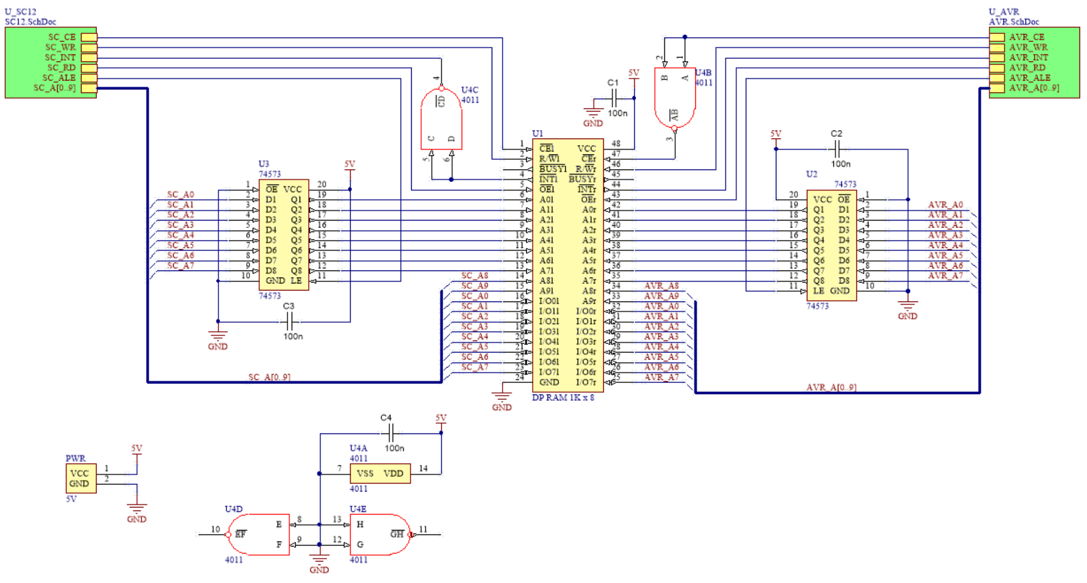
[2] github.com/adafruit/Adafruit_NeoPixel
[3] wp.josh.com/2014/05/13/ws2812 en cpldcpu.wordpress.com/2014/01/14/light_ws2812-
[4] github.com/cpldcpu/light_ws2812/tree/master/light_ws2812_AVR/Light_WS2812

4.3 De AVR software

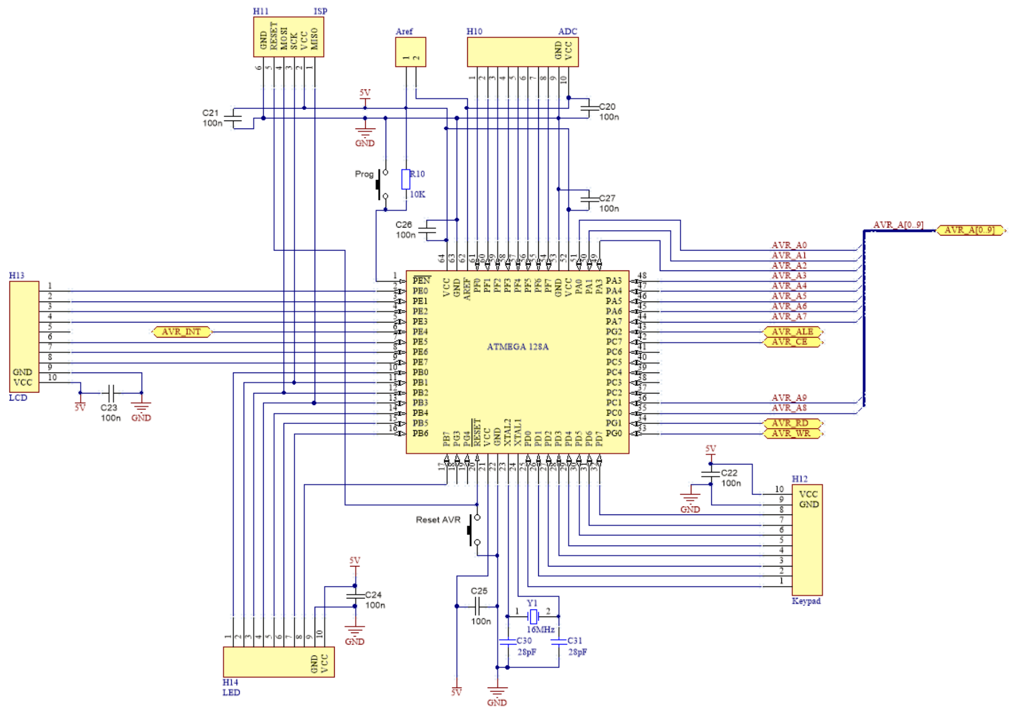
5 Besluit

6 Bijlagen

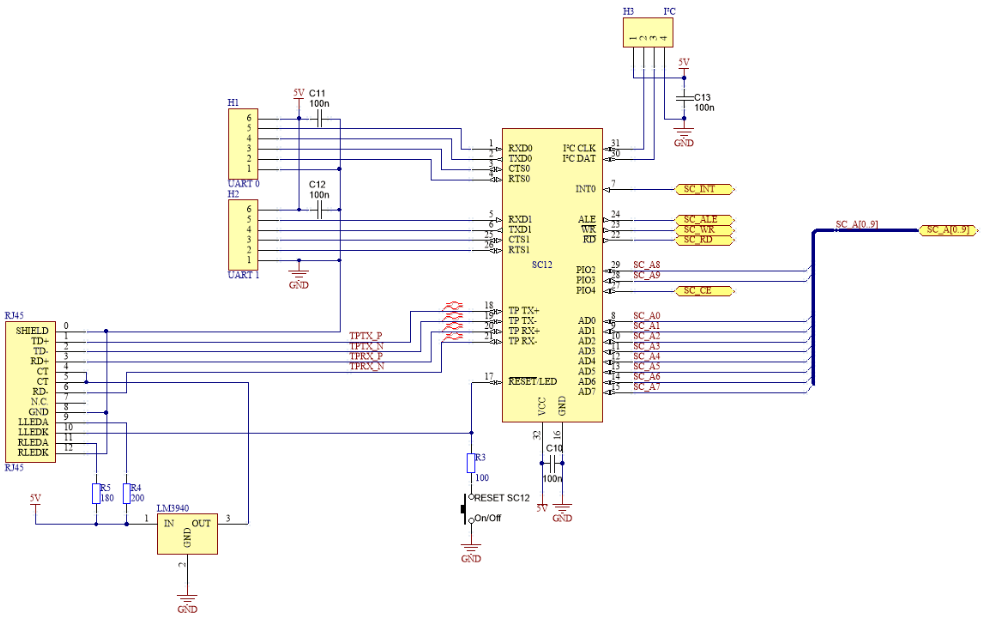
6.1 PCB Schema's & Layout



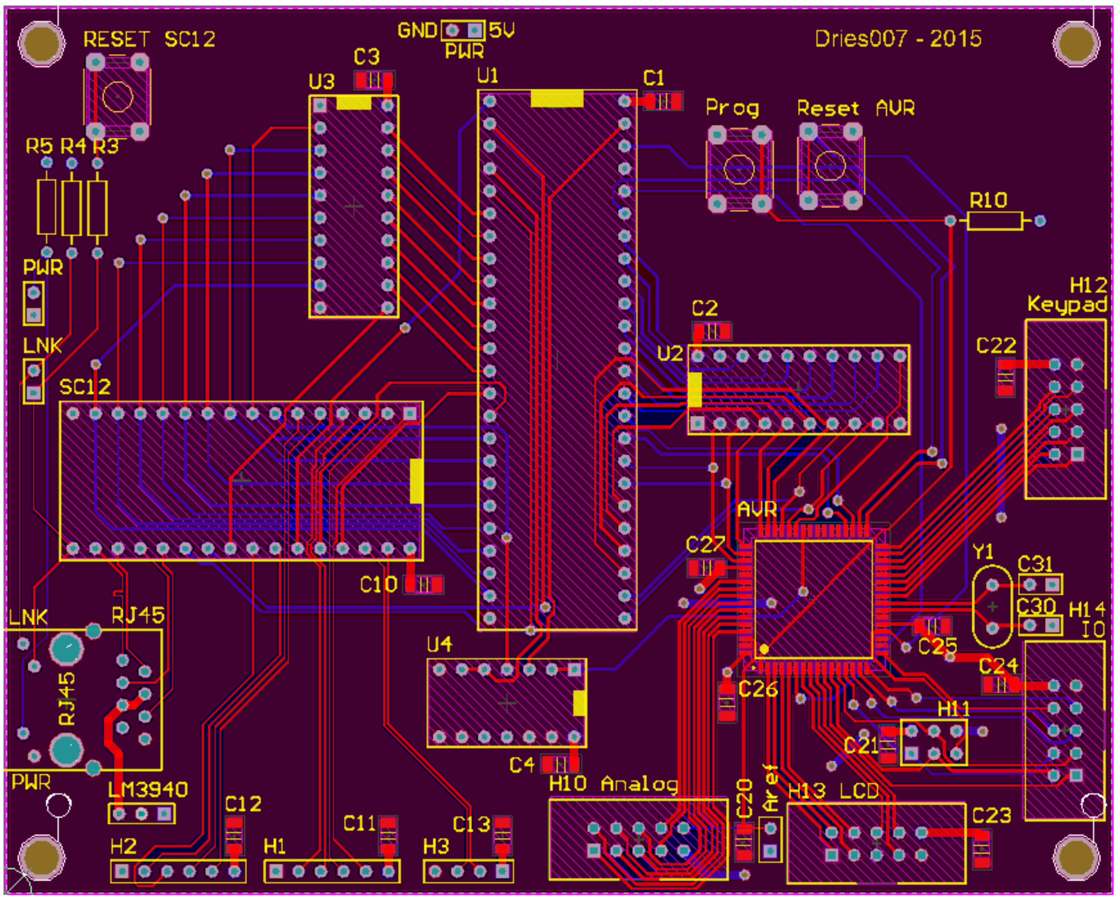
Figuur 6.1 Schema DP-RAM deel



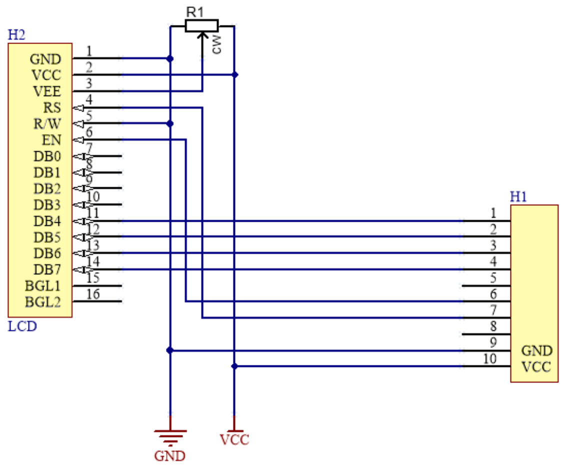
Figuur 6.2 Schema AVR deel



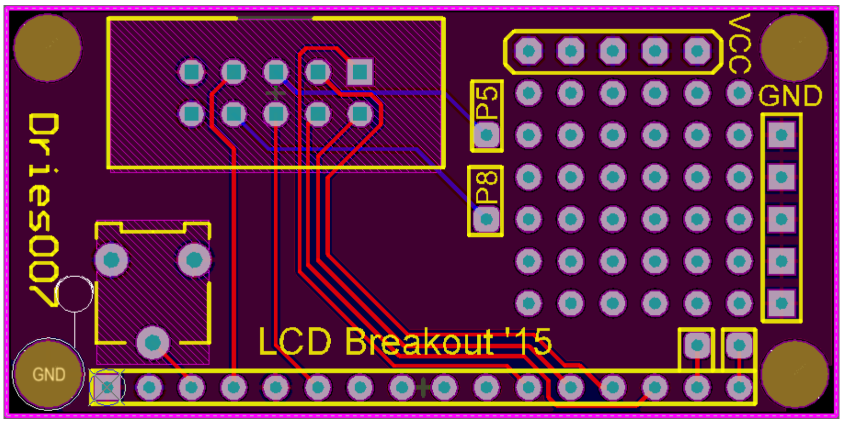
Figuur 6.3 Schema SC12 deel



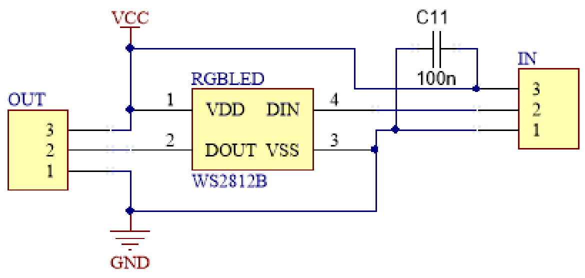
Figuur 6.4 Master PCB layout (125 x 100 mm)



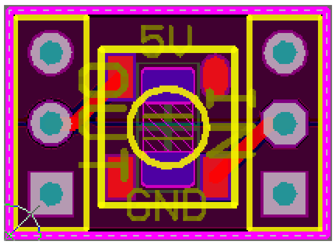
Figuur 6.5 Schema LCD-Breakout



Figuur 6.6 LCD-Breakout PCB layout (50 x 25 mm)



Figuur 6.7 WS2812B Schema



Figuur 6.8 WS2812B Layout (11 x 8 mm)

6.2 Broncode

De volledige broncode is ook beschikbaar op github.com/dries007/ModernMasterMind.

Mastermind.c draait op de SC12, AVR.c op de ATMega128.

Het originele HTML template is ook toegevoegd, aangezien dit gecomprimeerd bijna onleesbaaar is.

De cLib library die bij mastermind.h code hoord is beschikbaar op www.beck-ipc.com.

6.2.1 mastermind.h

```
#ifndef SRC_MASTERMIND_H_
#define SRC_MASTERMIND_H_

#pragma option -1 //create 80186 code

#include <clib.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <limits.h>
#include <dos.h>
#include <stdarg.h>
#include <ctype.h>
#include <rtos.h>
#include <i86.h>

#include "ramdump.h"
#include "httpcli.h"
#include "base64.h"
#include "dns.h"

/* ================= DEFINES ================= */

#define DEBUG 0

#define VERSION "0.2"
#define CYEAR "15"

#define TASK_STACKSIZE  2048

#define TCPIP_int 0xAC

#define LCD_LINE_SIZE 16
#define LCD_LINES 2

#define MAX_COLORS 8
#define COLORS 4
#define ROWS 12

#define STATE_NO_GAME 0
#define STATE_GAME_CONFIGURED 1
#define STATE_GAME_STARTED 2
#define STATE_GAME_OVER 3
#define STATE_GAME_WON 4

// amount of (positive) hours offset from GMT
#define TIMEZONE_OFFSET 2

// 170 Leds max (x 3 bytes = 0x1FE)
#define RAM_LEDS_START  0x000
#define RAM_LEDS_END    0x1FE
#define RAM_LEDS_AMOUNT 0x1FF
```

```
// 80 bytes of char buffer for LCD
#define RAM_LCD_START   0x200
#define RAM_LCD_END     0x250
#define RAM_LCD_CMD     0x251
// Mask for global LED dimming
#define RAM_LEDS_DIM    0x252
#define RAM_KP_LASTKEY  0x253

#define RAM_VERSION_1   0x300
#define RAM_VERSION_2   0x301

// Interrupt registers
#define RAM_INT_SEND    0x3FF
#define RAM_INT_GET     0x3FE

#define MAX_LEDS        (RAM_LEDS_END - RAM_LEDS_START)
#define MAX_LCD_CHARS   (RAM_LCD_END - RAM_LCD_START)

#define CMD_LEDS_SEND   0x01
#define CMD_LCD_CHAR    0x02
#define CMD_LCD_CMD     0x03
#define CMD_LCD_CL_PR   0x04
#define CMD_LCD_POS     0x05
#define CMD_LCD_BL_ON   0x06
#define CMD_LCD_BL_OFF  0x07

#define SATUS_KP_PRESS  0x01

#define NORMALIZE_ADDRESS(addr) ((addr & 0x0FF) | 0x100)
#define BANK_FROM_ADDRESS(addr) (addr >> 8)

/* ================= STRUCTS ================= */

typedef unsigned char byte;
typedef unsigned short address;

typedef struct
{
  unsigned long ip;
  char name[21];
} User;

typedef struct
{
  byte r;
  byte g;
  byte b;
} RGB;

typedef struct
{
  byte state;
  byte vsPlayer;
  User * host;
  byte colors;
  byte code[COLORS];
  byte nrOfGuesses;
  byte guesses[ROWS][COLORS + 2];
} Game;

struct userlist_el
{
  User user;
  struct userlist_el * next;
};

/* ================ METHODS ================ */
```

```

void endProgram();

User * getUserByIP(long far * ip);
User * getUserByName(char * name);
void addUser(long ip, char name[21]);

Game * getGame();
void resetGame();
void setRndCode(byte colors);
void guessRow(byte id);

void enableDatabus(); // Enables databus
byte readDatabus(address addr); // read byte from databus
void writeDatabus(address addr, byte value); // write byte to databus
//void initTime();

void clearLCD();
void setLCDLine(byte line, const char *string);
void setLCDLineFormat(byte line, const char *format, ...);

void installCGIMethods();
void removeCGIMethods();

void printAllUsers();

/* ================= GLOBALS ================= */

const RGB BLACK = { 0, 0, 0 };
const RGB WHITE = { 255, 255, 255 };

const RGB RED = { 255, 0, 0 };
const RGB GREEN = { 0, 255, 0 };
const RGB BLUE = { 0, 0, 255 };

const RGB PINK = { 255, 0, 255 };
const RGB AQUA = { 0, 255, 255 };
const RGB YELLOW = { 255, 255, 0 };

const RGB PURPLE = { 130, 0, 255 };
const RGB ORANGE = { 255, 130, 0 };

const RGB ALL_COLORS[10] = { { 255, 0, 0 }, { 0, 255, 0 }, { 0, 0, 255 }, {
    255, 0, 255 }, { 0, 255, 200 }, { 255, 255, 0 }, { 255, 255, 255 }, {
    255, 80, 0 }, { 0, 0, 0 } };
const char * ALL_COLOR_CLASSES[10] = { "red", "green", "blue", "pink",
    "aqua", "yellow", "white", "orange", "black" };

union REGS inregs;
union REGS outregs;
struct SREGS segregs;

Game game;

struct userlist_el * listHead = NULL;
struct userlist_el * listTail = NULL;

#endif /* SRC_MASTERMIND_H_ *
```

6.2.2 mastermind.c

```c
#include "mastermind.h"

/***********************************************************
 *                       USER RELATED
 ***********************************************************/

User * getUserByIP(long far * ip)
{
  struct userlist_el * current = listHead;
  while (current != NULL)
  {
    if (current->user.ip == *((unsigned long *) ip))
      return &(current->user);
    current = current->next;
  }
  return NULL;
}

User * getUserByName(char * name)
{
  for (int i = 0; name[i]; i++)
    name[i] = tolower(name[i]);

  struct userlist_el * current = listHead;
  while (current != NULL)
  {
    if (strcmp(current->user.name, name) == 0) return &(current->user);
    current = current->next;
  }
  return NULL;
}

void addUser(long ip, char name[21])
{
  for (int i = 0; name[i]; i++)
    name[i] = tolower(name[i]);
  struct userlist_el * newItem = (struct userlist_el *) malloc(
      sizeof(struct userlist_el));

  newItem->user.ip = ip;
  strcpy(newItem->user.name, name);

  if (listHead == NULL)
  {
    listHead = listTail = newItem;
  }
  else
  {
    listTail->next = newItem;
  }
}

void printAllUsers()
{
  if (listHead == NULL)
  {
    printf("No users in the user list.\n");
    return;
  }

  printf("User list:\n");
  struct userlist_el * current = listHead;
  while (current != NULL)
  {
    printf("Username: %s Remote IP: %d.%d.%d.%d\n", current->user.name,
        (int) ((current->user.ip & 0xFF000001) >> 24),
        (int) ((current->user.ip & 0x00FF0000l) >> 16),
        (int) ((current->user.ip & 0x0000FF00l) >> 8),
        (int) (current->user.ip & 0x000000FFl));
    current = current->next;
  }
}

/**********************************************************
 *                     LEDS RELATED
 **********************************************************/

address sendProper(byte row, address addr)
{
  for (byte p = 0; p < COLORS; p++)
  {
    RGB rgb = ALL_COLORS[game.guesses[row][p]];
    writeDatabus(addr++, rgb.r);
    writeDatabus(addr++, rgb.g);
    writeDatabus(addr++, rgb.b);
  }

  byte g = game.guesses[row][COLORS];
  byte r = game.guesses[row][COLORS + 1];

  for (byte p = 0; p < g; p++)
  {
    writeDatabus(addr++, GREEN.r);
    writeDatabus(addr++, GREEN.g);
    writeDatabus(addr++, GREEN.b);
  }

  for (byte p = 0; p < r; p++)
  {
    writeDatabus(addr++, YELLOW.r);
    writeDatabus(addr++, YELLOW.g);
    writeDatabus(addr++, YELLOW.b);
  }

  for (byte p = g + r; p < COLORS; p++)
  {
    writeDatabus(addr++, BLACK.r);
    writeDatabus(addr++, BLACK.g);
    writeDatabus(addr++, BLACK.b);
  }

  return addr;
}

address sendReverse(byte row, address addr)
{
  byte g = game.guesses[row][COLORS];
  byte r = game.guesses[row][COLORS + 1];

  for (byte p = g + r; p < COLORS; p++)
  {
    writeDatabus(addr++, BLACK.r);
    writeDatabus(addr++, BLACK.g);
    writeDatabus(addr++, BLACK.b);
  }

  for (byte p = 0; p < r; p++)
  {
    writeDatabus(addr++, YELLOW.r);
    writeDatabus(addr++, YELLOW.g);
    writeDatabus(addr++, YELLOW.b);
  }

  for (byte p = 0; p < g; p++)
  {
    writeDatabus(addr++, GREEN.r);
    writeDatabus(addr++, GREEN.g);
    writeDatabus(addr++, GREEN.b);
  }

  for (byte p = 0; p < COLORS; p++)
  {
    RGB rgb = ALL_COLORS[game.guesses[row][COLORS - 1 - p]];
    writeDatabus(addr++, rgb.r);
    writeDatabus(addr++, rgb.g);
    writeDatabus(addr++, rgb.b);
  }

  return addr;
}

void sendLEDS()
{
  address addr = RAM_LEDS_START;
  byte row = 0;
  while (row < ROWS)
  {
    addr = sendProper(row++, addr);
    addr = sendReverse(row++, addr);
  }
  writeDatabus(RAM_INT_SEND, CMD_LEDS_SEND);
}

/*************************************************************
 *                      GAME RELATED
 *************************************************************/

Game * getGame()
{
  return &game;
}

void resetGame()
{
  game.state = STATE_NO_GAME;
  game.nrOfGuesses = 0;
  for (int i = 0; i < ROWS; i++)
  {
    for (int j = 0; j < COLORS; j++)
    {
      game.guesses[i][j] = 9; // 9 = black
    }
    game.guesses[i][COLORS] = 0;
    game.guesses[i][COLORS + 1] = 0;
  }
  sendLEDS();
}

void setRndCode(byte colors)
{
  if (colors > MAX_COLORS) colors = MAX_COLORS;
  for (byte i = 0; i < COLORS; i++)
  {
    game.code[i] = rand() % colors;
  }
}

void guessRow(byte id)
{
  if (id >= ROWS)
  {
    game.state = STATE_GAME_OVER;
    return;
  }
  byte usedUpPins[COLORS];
  for (byte i = 0; i < COLORS; i++)
    usedUpPins[i] = 0;

  for (byte i = 0; i < COLORS; i++)
  {
    // Exact matches
    if (game.guesses[id][i] == game.code[i])
    {
      if (usedUpPins[i] == 1)
      {
        game.guesses[id][COLORS + 1]--;
      }

      usedUpPins[i] = 1;
      game.guesses[id][COLORS]++;
      if (game.guesses[id][COLORS] == COLORS)
      {
        game.state = STATE_GAME_WON;
      }
    }
    else
    {
      for (byte j = 0; j < COLORS; j++)
      {
        if (game.guesses[id][i] == game.code[j] && usedUpPins[j] == 0)
        {
          usedUpPins[j] = 1;
          game.guesses[id][COLORS + 1]++;
          break;
        }
      }
    }
  }
  sendLEDS();
}

/**************************************************************
 *                       DATA BUS RELATED
 **************************************************************/

void enableDatabus()
{
  pfe_enable_bus(0xFF, 1); // all 8 bits enabled with ALE
  pfe_enable_pcs(1); // Chip select 1 (PIO4)
  pfe_enable_pio(2, 5); // PIO2 = output, low
  pfe_enable_pio(3, 5); // PIO3 = output, low
}

byte readDatabus(address addr)
{
  byte bank = addr >> 8;
  pfe_enable_pio(2, bank & 0x01 ? 4 : 5); // if bank is 1 or 3, set PIO2
high, otherwise set PIO2 low
  pfe_enable_pio(3, bank & 0x02 ? 4 : 5); // if bank is 3 or 4, set PIO3
high, otherwise set PIO3 low
  return hal_read_bus((addr & 0x0FF) | 0x100, 0xFFFF, 0x0000); // Read data
bus on corrected address (always in 0x100..0x1FF range)
}

void writeDatabus(address addr, byte val)
{
  byte bank = addr >> 8;
  // if bank is 1 or 3, set PIO2 high, otherwise set PIO2 low
  pfe_enable_pio(2, bank & 0x01 ? 4 : 5);
  // if bank is 3 or 4, set PIO3 high, otherwise set PIO3 low
  pfe_enable_pio(3, bank & 0x02 ? 4 : 5);
  // Write to data bus on corrected address (always in 0x100..0x1FF range)
  hal_write_bus((addr & 0x0FF) | 0x100, val, 0xFFFF, 0x0000);
}

/**********************************************************
 *                      LCD RELATED
 **********************************************************/

void clearLCD()
{
  for (address addr = RAM_LCD_START; addr <= RAM_LCD_END; addr++)
  {
    writeDatabus(addr, ' ');
  }
  writeDatabus(RAM_LCD_CMD, 0x01);
  writeDatabus(RAM_INT_SEND, CMD_LCD_CMD);
}

void setLCDLine(byte line, const char * text)
{
  address offset = RAM_LCD_START;

#if LCD_LINES == 2
  if (line == 1 || line == 3) offset += 40;
#elif LCD_LINES == 4
  if (line % 2 != 0) offset += 40;
  if (line > 1) offset += 0x14;
#endif

  address i = 0;
  for (; i < strlen(text); i++) // chars
  {
    writeDatabus(i + offset, text[i]);
  }
  for (; i < LCD_LINE_SIZE; i++) // spaces
  {
    writeDatabus(i + offset, ' ');
  }
  writeDatabus(RAM_INT_SEND, CMD_LCD_CL_PR);
  delay(100);
}

void setLCDLineFormat(byte line, const char * format, ...)
{
  byte buffer[LCD_LINE_SIZE + 1];
  buffer[LCD_LINE_SIZE] = 0x00;

  /* Start magic */
  va_list aptr;
  va_start(aptr, format);
  vsprintf(buffer, format, aptr);
  va_end(aptr);
  /* End magic */

  setLCDLine(line, buffer);
}

/**********************************************************************
 *                                 TASKS
 **********************************************************************/

byte LCDupdateRunning;

```

```
void LCDupdate()
{
  LCDupdateRunning = 1;
  byte ip[16], oldIp[16];

  while (LCDupdateRunning)
  {
    Get_IPConfig(ip, NULL, NULL);

    if (strcmp(ip, oldIp) != 0)
    {
      strcpy(oldIp, ip);
      setLCDLine(1, ip);
    }
    RTX_Sleep_Time(2500);
  }
}

unsigned int LCDUpdate_stack[TASK_STACKSIZE / sizeof(unsigned int)];
int LCDupdateID;

TaskDefBlock LCDupdateTaskDefBlock = { LCDupdate, { 'L', 'C', 'D', ' ' },
    &LCDUpdate_stack[TASK_STACKSIZE / sizeof(unsigned int)], // top of stack
    TASK_STACKSIZE, // size of stack
    0, // attributes, not supported
    100, // lower priority than any system tasks
    0, // time slice (if any), not supported
    0, 0, 0, 0 // mailboxes
    };

/*************************************************************************
 *                                    MAIN
 ************************************************************************/

/*
 * Ends all tasks, returns focus and exits
 */
void endProgram()
{
  setLCDLine(0, "Shutdown issued");

  removeCGIMethods();

  printf("Gracefully ending all tasks...\n");

  LCDupdateRunning = 0; // tell tasks to stop

  RTX_Sleep_Time(3000); // give tasks time to end

  printf("Killing the non obedient tasks...\n");
  RTX_Delete_Task(LCDupdateID);

  printf("\nEND OF PROGRAM\n");
  // Release input/output
  BIOS_Set_Focus(FOCUS_BOTH);
  exit(0);
}

void test()
{
  writeDatabus(RAM_LEDS_DIM, 0xFF);
  writeDatabus(RAM_LEDS_AMOUNT, 100);

  address addr = RAM_LEDS_START;
  for (byte r = 0; r < ROWS; r++)
  {
    for (byte p = 0; p < COLORS * 2; p++)
    {
      RGB rgb = ALL_COLORS[rand() % MAX_COLORS];
      writeDatabus(addr++, rgb.r);
      writeDatabus(addr++, rgb.g);
      writeDatabus(addr++, rgb.b);
    }
  }
  writeDatabus(RAM_INT_SEND, CMD_LEDS_SEND);
  delay(1000);
}

void debugGameState()
{
  printf(
      "\nGame state: %d\nGame VS player: %d\nGame host: %s\n# colors:
%d\nCode: ",
      game.state, game.vsPlayer, game.host->name, game.colors);
  for (byte i = 0; i < COLORS; i++)
    printf("%s ", ALL_COLOR_CLASSES[game.code[i]]);
  printf("\n# of guesses: %d\nGuesses Table:\n", game.nrOfGuesses);
  for (byte r = 0; r < ROWS; r++)
  {
    printf("Guess #%d: ", r);
    for (byte c = 0; c < COLORS; c++)
      printf("%10s ", ALL_COLOR_CLASSES[game.guesses[r][c]]);
    printf(" Exact: %d Color: %d\n", game.guesses[r][COLORS],
        game.guesses[r][COLORS + 1]);
  }
  printf("Code: ");
  for (byte c = 0; c < COLORS; c++)
    printf("%10s ", ALL_COLOR_CLASSES[game.code[c]]);
  printf("\n\n");
}

void main()
{
  // Get focus
  BIOS_Set_Focus(FOCUS_APPLICATION);

  /**
   * INIT All of the things!
   */
  enableDatabus();

  writeDatabus(RAM_INT_SEND, CMD_LCD_BL_ON);

  writeDatabus(RAM_LEDS_DIM, 0xFF);
  writeDatabus(RAM_LEDS_AMOUNT, ROWS * 2 * COLORS);

  writeDatabus(RAM_LCD_CMD, 0x0C); // Blink off
  writeDatabus(RAM_INT_SEND, CMD_LCD_CMD);

  clearLCD();

  printf("\n\nAVR firmware version id: %d 0x%02x\n\n\n",
      readDatabus(RAM_VERSION_1), readDatabus(RAM_VERSION_2));
  setLCDLine(0, "MMM by Dries007");
  setLCDLine(1, "Booting...");

  // Ethernet connection check
  if (BIOS_Ethernet_State(NULL, NULL))
  {
    setLCDLine(0, "ERROR");
    setLCDLine(1, "NO ETHERNET!");

    while (1)
    {
```

```
    test();
  }

  return;
}

/**
 * RUN ALL TASKS
 */
int result = RTX_Create_Task(&LCDupdateID, &LCDupdateTaskDefBlock);

if (result != 0)
{
  printf("Creating/restart LCDupdate failed %d, exit program\n", result);
  //delete task1
  RTX_Delete_Task(LCDupdateID);
  endProgram();
}

/**
 * CGI methods
 */

printf("Installing CGI methods\n");
installCGIMethods();

printf("Reset Game status\n");
resetGame();

/*
 * MENU
 */
byte key;
while (1)
{
  printf("-~= Menu =~-\n");
  printf("------------\n");
  printf("[X] End program\n");
  printf("[R] Reboot\n");
  printf("[D] Debug RAM Dump\n");
  printf("[S] Set RAM manually\n");
  printf("[G] Debug Game State\n");
  printf("[U] Print all known users\n");
  printf("[I] Interrupt test to AVR\n");

  scanf("%c%*c", &key);

  switch (key & ~0x20)
  {
    case 'X':
      endProgram();
      break;
    case 'R':
      BIOS_Reboot();
      break;
    case 'D':
      ramdump();
      break;
    case 'S':
      manualram();
      break;
    case 'G':
      debugGameState();
      break;
    case 'U':
      printAllUsers();
      break;
      case 'I':
        test();
        break;
      default:
        printf("Char not in menu: %c\n", key);
    }
  }
}

/***********************************************************************
 *                                  WEB
 ***********************************************************************/

/*************************************************************
 *                        TEMPLATE PARTS
 *************************************************************/

char * pageHeader =
    "<!doctype html><html><head><meta charset='us-ascii'/><meta
name='viewport' content='width=400' /><title>Mastermind</title><link
href='http://fonts.googleapis.com/css?family=Open+Sans:600,400'
rel='stylesheet' type='text/css'><style type='text/css'>body,html{font-
family:'Open Sans',sans-serif;margin:0 auto;padding:0;height:100%%;min-
height:100%%;position:relative;max-width:500px}#wrapper{padding:10px 10px
30px}.center{text-align:center}.black{background-
color:#000;color:#fff}.white{background-color:#fff}.orange{background-
color:orange}.purple{background-color:purple;color:#fff}.yellow{background-
color:#ff0}.aqua{background-color:#0ff}.pink{background-
color:#ff1493}.blue{background-color:#00f;color:#fff}.green{background-
color:green;color:#fff}.red{background-color:red}header h1{margin:1px}header
ul{margin:1px;padding:1px}header ul li{display:inline;padding:0
10px;margin:1px;border:1px solid #000;border-radius:5px;box-shadow:2px 2px
3px #888}header ul li a{tekst-
decoration:none;color:#000}.guesses{width:100%%;text-align:center;;border-
collapse:collapse}.guesses .txt{padding:0 10px}.guesses * tr td{border:1px
solid #000}footer{position:absolute;bottom:0;height:30px;padding:0
10px}footer a{text-decoration:none;color:#d3d3d3;font-
size:smaller}input[type=submit], .btn{display:inline;padding:3px
10px;margin:1px;border:1px solid #000;border-radius:5px;box-shadow:2px 2px
3px #888;background:#fff;text-
decoration:none;color:#000}</style></head><body><div id='wrapper'>";

char * pageFooter =
    "</div><footer><a class='center' href='http://www.dries007.net/'>&copy;
Dries007.net - 2015</a></footer></body></html>";

char * pickUsername =
    "<h2>Welcome new player!</h2><p>Before you can play, you need to pick a
username:</p><form method='post' action='pickUsername'><input type='text'
name='username' maxlength='20'/><input type='submit'
value='Check'/></form>";

char * noGameYet = "<p>No game is going yet, but you can start one!</p>";

char * gameAvailable =
    "<p>A game is currently being played. Go ahead an join!</p>";

/**
 * Needs 2 extra strings per count. First string is URL, second is name.
 */
void addMenuItems(char * buffer, byte count, ...)
{
  strcat(buffer, "<header class='center'><h1>Mastermind</h1><ul>");

  va_list ap;
  va_start(ap, count);

  for (byte i = 0; i < count; i++)
  {
    strcat(buffer, "<li><a href='");
    strcat(buffer, va_arg(ap, char *));
    strcat(buffer, "'>");
    strcat(buffer, va_arg(ap, char *));
    strcat(buffer, "</a></li>");
  }

  va_end(ap);
  strcat(buffer, "</ul></header>");
}

/*********************************************************
 *                       HOME (GET)
 *********************************************************/

void huge _pascal _saveregs cgiHomeFunction(rpCgiPtr CgiRequest)
{
  static char pageBuffer[2048]; // Buffer to contain web page
  //char tmpBuffer[512]; // Buffer for string manipulation functions

  sprintf(pageBuffer, pageHeader);

  User * user = getUserByIP(CgiRequest->fRemoteIPPtr);
  if (user == NULL)
  {
    addMenuItems(pageBuffer, 0);
    strcat(pageBuffer, pickUsername);
  }
  else
  {
    if (getGame()->state == STATE_NO_GAME) addMenuItems(pageBuffer, 1,
        "start", "Start a game");
    else addMenuItems(pageBuffer, 1, "play", "Play");

    strcat(pageBuffer, "<h2>Welcome ");
    strcat(pageBuffer, user->name);
    strcat(pageBuffer, "</h2>");

    if (getGame()->state == STATE_NO_GAME) strcat(pageBuffer, noGameYet);
    else strcat(pageBuffer, gameAvailable);
  }

  strcat(pageBuffer, pageFooter);

  CgiRequest->fHttpResponse = CgiHttpOk;
  CgiRequest->fDataType = CGIDataTypeHtml;
  CgiRequest->fResponseBufferPtr = pageBuffer;
  CgiRequest->fResponseBufferLength = strlen(pageBuffer);
}

/*********************************************************
 *                       PICK USERNAME (POST)
 *********************************************************/

void huge _pascal _saveregs cgiPickUsernameFunction(rpCgiPtr CgiRequest)
{
  static char pageBuffer[2048]; // Buffer to contain web page
  //char tmpBuffer[512]; // Buffer for string manipulation functions

  sprintf(pageBuffer, pageHeader);

  char * name;
  char * value;
  while (CGI_GetArgument(&name, &value, CgiRequest) == CGI_ARGUMENT_ERR_OK)
  {
```

```
  if (strcmp(name, "username") == 0)
  {
   if (getUserByName(value) != NULL)
   {
    addMenuItems(pageBuffer, 0);

    strcat(pageBuffer, "<p>Sorry, ");
    strcat(pageBuffer, value);
    strcat(pageBuffer,
      " is already in use. Pick another name please:</p><form
method='post' action='pickUsername'><input type='text'
name='username'/><input type='submit' value='Check'/></form>");
   }
   else
   {
    addUser(*((long *) CgiRequest->fRemoteIPPtr), value);

    if (getGame()->state == STATE_NO_GAME) addMenuItems(pageBuffer, 1,
      "start", "Start a game");
    else addMenuItems(pageBuffer, 1, "play", "Play");

    strcat(pageBuffer, "<p>You are now known as ");
    strcat(pageBuffer, value);
    strcat(pageBuffer, "!</p>");

    if (getGame()->state == STATE_NO_GAME) strcat(pageBuffer,
      noGameYet);
    else strcat(pageBuffer, gameAvailable);
   }
  }
 }

 strcat(pageBuffer, pageFooter);

 CgiRequest->fHttpResponse = CgiHttpOk;
 CgiRequest->fDataType = CGIDataTypeHtml;
 CgiRequest->fResponseBufferPtr = pageBuffer;
 CgiRequest->fResponseBufferLength = strlen(pageBuffer);
}

/*******************************************************
 *                      START (BOTH)
 *******************************************************/

void huge _pascal _saveregs cgiStartFunction(rpCgiPtr CgiRequest)
{
 static char pageBuffer[2048]; // Buffer to contain web page
 char tmpBuffer[512]; // Buffer for string manipulation functions

 sprintf(pageBuffer, pageHeader);

 User * user = getUserByIP(CgiRequest->fRemoteIPPtr);
 Game * game = getGame();
 if (user == NULL)
 {
  addMenuItems(pageBuffer, 0);
  strcat(pageBuffer, pickUsername);
 }
 else if (game->state == STATE_NO_GAME
    || game->state == STATE_GAME_CONFIGURED) // If game is not (fully)
configured yet
 {
  char * name;
  char * value;
  while (CGI_GetArgument(&name, &value, CgiRequest)
    == CGI_ARGUMENT_ERR_OK) // Argument parse loop
  {
   if (strcmp(name, "mode") == 0) // Gamemode
   {
    game->vsPlayer = strcmp(value, "Player") == 0;
    game->state = STATE_GAME_CONFIGURED;
   }
   else if (strcmp(name, "colors") == 0) // # of colors
   {
    game->colors = atoi(value);
    game->state = STATE_GAME_CONFIGURED;
   }
   else // Colors of code
   {
    int i;
    sscanf(name, "c%d", &i);
    game->code[i] = atoi(value);
    game->state = STATE_GAME_STARTED;
   }
  }

  if (game->state == STATE_GAME_CONFIGURED) // If game is partially
configured (argument parser above)
  {
   if (game->vsPlayer) // Print color picker code
   {
    game->host = user;
    addMenuItems(pageBuffer, 0);
    strcat(pageBuffer,
      "<p>Pick your code:</p><form method='get' action='start'>");
    for (byte i = 0; i < 4; i++) // Color picker 1 -> 4
    {
     sprintf(tmpBuffer, "<select name='c%d'>", i);
     strcat(pageBuffer, tmpBuffer);

     for (byte c = 0; c < game->colors; c++)
     {
      sprintf(tmpBuffer, "<option value='%d' class='%s'>%s</option>",
        c, ALL_COLOR_CLASSES[c], ALL_COLOR_CLASSES[c]);
      strcat(pageBuffer, tmpBuffer);
     }

     strcat(pageBuffer, "</select>");
    }
    strcat(pageBuffer,
      "<input type='submit' value='Choose!'/></form>");
   }
   else // VS computer
   {
    addMenuItems(pageBuffer, 1, "play", "Play");
    strcat(pageBuffer, "<h2>Game started!</h2>");
    setRndCode(game->colors);
    game->state = STATE_GAME_STARTED;
   }
  }
  else if (game->state == STATE_GAME_STARTED) // Game started
  {
   addMenuItems(pageBuffer, 1, "play", "Play");
   strcat(pageBuffer, "<h2>Game started!</h2>");
  }
  else // New game form
  {
   addMenuItems(pageBuffer, 0);
   strcat(pageBuffer,
     "<h2>Start a new game</h2><form method='get' action='start'><p>
Player(s) VS <label><input type='radio' name='mode' value='Player' checked/>
Host</label><label><input type='radio' name='mode' value='Computer'/>
Computer</label></p><p><label for='colors'># of colors: </label><select
id='colors'
name='colors'><option>4</option><option>6</option><option>8</option></select
></p><input type='submit' value='Go!'/></form>");
    }
  }
  else // Already going
  {
    addMenuItems(pageBuffer, 1, "play", "Play");
    strcat(pageBuffer,
        "<h2>Start a new game</h2><p>A game has already been started.</p>");
  }

  strcat(pageBuffer, pageFooter);

  CgiRequest->fHttpResponse = CgiHttpOk;
  CgiRequest->fDataType = CGIDataTypeHtml;
  CgiRequest->fResponseBufferPtr = pageBuffer;
  CgiRequest->fResponseBufferLength = strlen(pageBuffer);
}

/**********************************************************
 *                      PLAY (GET)
 **********************************************************/

void huge _pascal _saveregs cgiPlayFunction(rpCgiPtr CgiRequest)
{
  static char pageBuffer[2048]; // Buffer to contain web page
  char tmpBuffer[512]; // Buffer for string manipulation functions

  sprintf(pageBuffer, pageHeader);

  User * user = getUserByIP(CgiRequest->fRemoteIPPtr);
  Game * game = getGame();

  if (user == NULL)
  {
    addMenuItems(pageBuffer, 0);
    strcat(pageBuffer, pickUsername);
  }
  else if (game->state == STATE_NO_GAME) // If game is not configured yet
  {
    addMenuItems(pageBuffer, 1, "start", "Start a game");
    strcat(pageBuffer, noGameYet);
  }
  else
  {
    addMenuItems(pageBuffer, 0);

    if (game->state == STATE_GAME_STARTED)
    {
      // Process guess, if any
      char * name;
      char * value;
      byte i = 0xFF;
      while (CGI_GetArgument(&name, &value, CgiRequest)
          == CGI_ARGUMENT_ERR_OK)
      {
        int p, c; //p = position, c = color id
        sscanf(name, "c%d", &p);
        c = atoi(value);
        if (i == 0xFF) i = game->nrOfGuesses++;
        game->guesses[i][p] = c;
      }
      if (i != 0xFF) guessRow(i);
    }

    // Display guess table

    strcat(pageBuffer,
        "<p>Guesses:</p><table class='guesses' border> <tr> <th
class='txt'>#</th>");
    for (byte c = 0; c < COLORS; c++)
      strcat(pageBuffer, "<th style='min-width: 50px;'></th>");
    strcat(pageBuffer,
        "<th class='txt'>Exact</th> <th class='txt'>Color</th> </tr>");

    for (byte i = 0; i < game->nrOfGuesses; i++)
    {
      sprintf(tmpBuffer, "<tr><td style='padding: 0 10px'>%d</td>", i);
      strcat(pageBuffer, tmpBuffer);

      for (byte c = 0; c < COLORS; c++)
      {
        char * color = ALL_COLOR_CLASSES[game->guesses[i][c]];
        sprintf(tmpBuffer, "<td class='%s'>%s</td>", color, color);
        strcat(pageBuffer, tmpBuffer);
      }
      sprintf(tmpBuffer, "<td>%d</td><td>%d</td></tr>",
          game->guesses[i][COLORS], game->guesses[i][COLORS + 1]);
      strcat(pageBuffer, tmpBuffer);
    }

    strcat(pageBuffer, "</table>");

    if (game->state == STATE_GAME_OVER)
    {
      strcat(pageBuffer,
          "<p>Game over! The host/computer won!</p><a href='reset'
class='btn'>Reset</a>");
    }
    else if (game->state == STATE_GAME_WON)
    {
      strcat(pageBuffer,
          "<p>Game over! The codebreaker(s) won!</p><a href='reset'
class='btn'>Reset</a>");
    }
    else if (game->vsPlayer && game->host == user)
    {
      strcat(pageBuffer, "<p>You picked the code, you can't guess.</p>");
    }
    else if (game->state == STATE_GAME_STARTED) // Let user make guess
    {
      strcat(pageBuffer,
          "<p>Make a guess:</p><form method='get' action='play'>");
      for (byte i = 0; i < COLORS; i++) // Color picker 1 -> 4
      {
        sprintf(tmpBuffer, "<select name='c%d'>", i);
        strcat(pageBuffer, tmpBuffer);

        for (byte c = 0; c < game->colors; c++)
        {
          byte selected = game->nrOfGuesses != 0
              && game->guesses[game->nrOfGuesses - 1][i] == c;
          sprintf(tmpBuffer,
              "<option value='%d' class='%s' %s >%s</option>", c,
              ALL_COLOR_CLASSES[c], selected ? "selected" : "",
              ALL_COLOR_CLASSES[c]);
          strcat(pageBuffer, tmpBuffer);
        }

        strcat(pageBuffer, "</select>");
      }
      strcat(pageBuffer, "<input type='submit' value='Choose!'/></form>");
    }
    else
    {
      strcat(pageBuffer,
          "<p>Code is not yet picked. Refresh the page to get a status
update.</p>");
    }
  }
  strcat(pageBuffer, pageFooter);

  CgiRequest->fHttpResponse = CgiHttpOk;
  CgiRequest->fDataType = CGIDataTypeHtml;
  CgiRequest->fResponseBufferPtr = pageBuffer;
  CgiRequest->fResponseBufferLength = strlen(pageBuffer);
}

/**********************************************************
 *                       RESET (GET)
 **********************************************************/

void huge _pascal _saveregs cgiResetFunction(rpCgiPtr CgiRequest)
{
  static char pageBuffer[2048]; // Buffer to contain web page
  char tmpBuffer[512]; // Buffer for string manipulation functions

  sprintf(pageBuffer, pageHeader);

  User * user = getUserByIP(CgiRequest->fRemoteIPPtr);
  Game * game = getGame();

  if (user == NULL)
  {
    addMenuItems(pageBuffer, 0);
    strcat(pageBuffer, pickUsername);
  }
  else if (game->state == STATE_GAME_OVER || game->state == STATE_GAME_WON)
// If game done
  {
    resetGame();

    addMenuItems(pageBuffer, 1, "start", "Start a game");
    strcat(pageBuffer, "<p>The game has been reset.</p>");
  }
  else
  {
    strcat(pageBuffer, "<p>Incorrect game state.</p>");
  }

  strcat(pageBuffer, pageFooter);

  CgiRequest->fHttpResponse = CgiHttpOk;
  CgiRequest->fDataType = CGIDataTypeHtml;
  CgiRequest->fResponseBufferPtr = pageBuffer;
  CgiRequest->fResponseBufferLength = strlen(pageBuffer);
}

/**********************************************************
 *                 ALL INSTALL / REMOVE LOGIC
 **********************************************************/

typedef void huge _pascal _saveregs (*CGIfn)(rpCgiPtr); // Because function
pointer syntax in unreadable

char *cgiNames[] = { "home", "pickUsername", "start", "play", "reset" };
int cgiMethods[] = { CgiHttpGet, CgiHttpPost, CgiHttpGet, CgiHttpGet,
    CgiHttpGet };
CGIfn cgiFunctions[] = { cgiHomeFunction, cgiPickUsernameFunction,
    cgiStartFunction, cgiPlayFunction, cgiResetFunction };
```

```
void installCGIMethods()
{
  CGI_Entry cgiEntry;

  for (byte i = 0; i < 5; i++)
  {
    cgiEntry.PathPtr = cgiNames[i];
    cgiEntry.CgiFuncPtr = cgiFunctions[i];
    cgiEntry.method = cgiMethods[i];

    if (CGI_Install(&cgiEntry) != 0)
    {
      printf("Installing CGI function %s failed\n", cgiEntry.PathPtr);
      endProgram();
    }
  }
}

void removeCGIMethods()
{
  byte n = sizeof(cgiMethods) / sizeof(int);
  for (byte i = 0; i < n; i++)
  {
    if (CGI_Delete(cgiNames[i]))
    {
      printf("Removing %s failed\n", cgiNames[i]);
    }
  }

```

6.2.3 HTML template

Dit is de niet gecondenseerde versie van de HTML code gebruikt in *mastermind.c* regel 554 t.e.m. 576.

```
<!DOCTYPE html>
<html>
    <head>
        <meta charset='us-ascii'>
        <meta content='width=400' name='viewport'>
        <title>
            Mastermind
        </title>
        <link
href='http://fonts.googleapis.com/css?family=Open+Sans:600,400'
rel='stylesheet' type='text/css'>
        <style type='text/css'>
            body,html {
                font-family:'Open Sans',sans-serif;
                margin:0 auto;
                padding:0;
                height:100%%;
                min-height:100%%;
                position:relative;
                max-width:500px
            }
            header ul li {
                display:inline;
                padding:0 10px;
                margin:1px;
                border:1px solid #000;
                border-radius:5px;
                box-shadow:2px 2px 3px #888
            }
            guesses {
                width:100%%;
                text-align:center;
                border-collapse:collapse
            }
            footer {
                position:absolute;
                bottom:0;
                height:30px;
                padding:0 10px
            }
            footer a {
                text-decoration:none;
                color:#d3d3d3;
                font-size:smaller
            }
            input[type=submit],.btn {
                display:inline;
                padding:3px 10px;
                margin:1px;
                border:1px solid #000;
                border-radius:5px;
                box-shadow:2px 2px 3px #888;
                background:#fff;
                text-decoration:none;
                color:#000
            }
            #wrapper { padding:10px 10px 30px }
           .center { text-align:center }
           .black { background-color:#000; color:#fff }
           .white { background-color:#fff }
           .orange { background-color:orange }
```

```html
            .purple { background-color:purple; color:#fff }
            .yellow { background-color:#ff0 }
            .aqua { background-color:#0ff }
            .pink { background-color:#ff1493 }
            .blue { background-color:#00f; color:#fff }
            .green { background-color:green; color:#fff }
            .red { background-color:red }
            header h1 { margin:1px }
            header ul { margin:1px; padding:1px }
            header ul li a { tekst-decoration:none; color:#000 }
            guesses .txt { padding:0 10px }
            guesses * tr td { border:1px solid #000 }
        </style>
    </head>
    <body>
        <div id='wrapper'></div>
        <footer>
            <a class='center' href='http://www.dries007.net/'>&copy;
Dries007.net - 2015</a>
        </footer>
    </body>
</html>
```

6.2.4 AVR.h

```
#ifndef AVR_H_
#define AVR_H_

#define DEBUG 0

/* =============== PORT CONFIG ============== */
// Mask to eliminate INT4
#define   LCD_PORT     PORTB
#define   LCD_DDR      DDRB
// KP = Keypad
#define   KP_PORT      PORTD
#define   KP_DDR       DDRD
#define   KP_PIN       PIND
// WS2812
#define LEDS_PORT      PORTE
#define LEDS_DDR       DDRE
#define LEDS_PIN       7

/* ============== RAM ADDRESSES ============= */
// Offset for External RAM
#define RAM_OFFSET     0x8000
// 170 Leds max (x 3 bytes = 0x1FE)
#define RAM_LEDS_START (RAM_OFFSET + 0x000)
#define RAM_LEDS_END   (RAM_OFFSET + 0x1FE)
#define RAM_LEDS_AMOUNT(RAM_OFFSET + 0x1FF)
// 80 bytes of char buffer for LCD
#define RAM_LCD_START  (RAM_OFFSET + 0x200)
#define RAM_LCD_END    (RAM_OFFSET + 0x250)
#define RAM_LCD_CMD    (RAM_OFFSET + 0x251)
// Mask for global LED dimming
#define RAM_LEDS_DIM   (RAM_OFFSET + 0x252)
#define RAM_KP_LASTKEY (RAM_OFFSET + 0x253)

#define RAM_VERSION_1  (RAM_OFFSET + 0x300)
#define RAM_VERSION_2  (RAM_OFFSET + 0x301)

// Interrupt registers
#define RAM_INT_SEND   (RAM_OFFSET + 0x3FE)
#define RAM_INT_GET    (RAM_OFFSET + 0x3FF)

#define MAX_LEDS       ((uint8_t)(RAM_LEDS_END - RAM_LEDS_START))
#define MAX_LCD_CHARS  ((uint8_t)(RAM_LCD_END - RAM_LCD_START))

/* ================ CMD CODES =============== */
#define CMD_LEDS_SEND  0x01     // Clock out LEDS
#define CMD_LCD_CHAR   0x02     // Print char buffer to LCD
#define CMD_LCD_CMD    0x03     // Send instruction byte to LCD
#define CMD_LCD_CL_PR  0x04     // Send clear + print out char buffer to LCD
#define CMD_LCD_POS    0x05     // Set LCD cursor to position
#define CMD_LCD_BL_ON  0x06     // Set LCD_BACKLIGHT = 1
#define CMD_LCD_BL_OFF 0x07     // Set LCD_BACKLIGHT = 0

#define SATUS_KP_PRESS 0x01     // Key was pressed

/* ================= MACROS ================= */
/*
   !WARNING! The data-lines on my custom PCB are flipped on the AVR side.
   This means that these macros use the '__builtin_avr_insert_bits' macro to
flip the data read/written from/to the DP-RAM.
   If you don't need this, replace '__builtin_avr_insert_bits (0x01234567,
{value}, 0)' with '{value}'.
*/
#define PONTER_RAM(addr)        ( ((volatile uint8_t *) addr) )
#define READ_RAM(addr)          ( __builtin_avr_insert_bits (0x01234567,
*PONTER_RAM(addr), 0) )
#define WRITE_RAM(addr, val)    { *PONTER_RAM(addr) =
__builtin_avr_insert_bits (0x01234567, val, 0); }

/* ================ STRUCTS =============== */
// Correct byte order!
struct cRGB { uint8_t g; uint8_t r; uint8_t b; };

/* ================ GLOBALS =============== */
struct cRGB LEDS[MAX_LEDS]; // LED data, in correct byte order
uint8_t LCD_BACKLIGHT = 0; // LCD back light pin status (pin 7)

/* =============== FUNCTIONS ============== */

/* ---------------- inits ----------------
 * Parameters: N/a
 * Actions:
 * -  Enable External Memory Interface
 * -  Set `LCD_PORT` as output (with `LCD_MASK`)
 * -  Set `KP_PORT`.[0->3] as output
 * -  Set `KP_PORT`.[4->8] as input
 * -  Set `LEDS_PORT`.`LEDS_PIN` as output
 * -  Init & Clear LCD
 *  -  Backlight LCD ON
 *  -  LCD Cursor OFF
 */
void inline inits();

/* ---------------- readMatrix ----------------
 * Parameters:
 * -   matrix          Pin readout of the matrix port (1 = active, invert
when using pull-ups)
 * Actions:
 * -  Convert matrix code to ACSII
 * Matrix layout:
 *    Bit | 5 | 6 | 7 | 8
 *    ----+---+---+---+---
 *      1 | 1 | 2 | 3 | A
 *      2 | 4 | 5 | 6 | B
 *      3 | 7 | 8 | 9 | C
 *      4 | * | 0 | # | D
 * Pressing 2 buttons at once results in 0x00, same as no button pressed
 */
uint8_t inline readMatrix(uint8_t matrix);

/* ---------------- sendLEDS ----------------
 * Parameters:
 * -  amountOfLeds     The amount of led information to send
 * Actions:
 * -  Send LED data in `LEDS` to `LEDS_PORT`.`LEDS_PIN`
 * -  Delay 50µs for reset pulse
 * Prerequisites:
 * -  `LEDS_PORT`.`LEDS_PIN` has been set as output
 */
void inline sendLEDS(uint16_t amountOfLeds);

/* ---------------- sendLCDNible ----------------
 * Parameters:
 * -  data         Populate 4 lower bits
 * -  rs           1 for character, 0 for instruction
 * Actions:
 * -  Mask data with 0x0F
 * -  Set data bit 7 (Backlight) to `LCD_BACKLIGHT`
 * -  Set data bit 6 (RegisterSelect) to`rs`
 * -  Set data bit 5 (Enable) to 1
 * -  Set data bit 4 (INT4) to 1 (for Pull-up)
 * -  Write data to `LCD_PORT`
 * -  delay 1 µs
 * -  Toggle bit 5 (Enable)
 * -  delay 2 µs
 */
void sendLCDNible(uint8_t data, uint8_t rs);

/* ---------------- sendLCDInstructionByte ----------------
 * Parameters:
 * -  data          Data to send to the instruction register
 *  Actions:
 * -  Call sendLCDNible(data >> 4, 0)
 * -  Call sendLCDNible(data, 0)
 * -  delay 50µs
 */
void sendLCDInstructionByte(uint8_t data);

/* ---------------- sendLCDCharacterByte ----------------
 * Parameters:
 * -  data          Data to send to the character register
 *  Actions:
 * -  Call sendLCDNible(data >> 4, 1)
 * -  Call sendLCDNible(data, 1)
 * -  delay 50µs
 */
void sendLCDCharacterByte(char data);

/* ---------------- sendLCDBuffer ----------------
 * Parameters:
 * -  *buffer          Pointer to character buffer
 *  Actions:
 * -  For every character in the buffer or until `MAX_LCD_CHARS` is reached:
 *     -  Call sendLCDCharacterByte(data)
 */
void sendLCDBuffer(char * buffer);

/* ############## START SECTION WS2812 DRIVER ##############
 * Original Source:    https://github.com/cpldcpu/light_ws2812/
 * Original Author:    Tim (cpldcpu@gmail.com)
 * Original License:   GNU GPL V2
(https://github.com/cpldcpu/light_ws2812/blob/master/License.txt)
 *     This license still applies to everything between the "WS2812 DRIVER"
section lines.
 *
 * Modifications by Dries007:
 * -  Changed configuration
 * -  Merged library into single set of source and header files
 */
// Timing in ns
#define w_zeropulse   350
#define w_onepulse    900
#define w_totalperiod 1250

// Fixed cycles used by the inner loop
#define w_fixedlow    2
#define w_fixedhigh   4
#define w_fixedtotal  8

// Insert NOPs to match the timing, if possible
#define w_zerocycles    (((F_CPU/1000)*w_zeropulse          )/1000000)
#define w_onecycles     (((F_CPU/1000)*w_onepulse    +500000)/1000000)
#define w_totalcycles   (((F_CPU/1000)*w_totalperiod +500000)/1000000)

// w1 - nops between rising edge and falling edge - low
#define w1 (w_zerocycles-w_fixedlow)
// w2   nops between fe low and fe high
#define w2 (w_onecycles-w_fixedhigh-w1)
// w3   nops to complete loop
#define w3 (w_totalcycles-w_fixedtotal-w1-w2)

```

```
#if w1>0
  #define w1_nops w1
#else
  #define w1_nops  0
#endif

// The only critical timing parameter is the minimum pulse length of the "0"
// Warn or throw error if this timing can not be met with current F_CPU
settings.
#define w_lowtime ((w1_nops+w_fixedlow)*1000000)/(F_CPU/1000)
#if w_lowtime>550
   #error "WS2812 DRIVER: Sorry, the clock speed is too low. Did you set
F_CPU correctly?"
#elif w_lowtime>450
   #warning "WS2812 DRIVER: The timing is critical and may only work on
WS2812B, not on WS2812(S)."
   #warning "Please consider a higher clockspeed, if possible"
#endif

#if w2>0
#define w2_nops w2
#else
#define w2_nops  0
#endif

#if w3>0
#define w3_nops w3
#else
#define w3_nops  0
#endif

#define w_nop1  "nop      \n\t"
#define w_nop2  "rjmp .+0 \n\t"
#define w_nop4  w_nop2 w_nop2
#define w_nop8  w_nop4 w_nop4
#define w_nop16 w_nop8 w_nop8

/* ############## END SECTION WS2812 DRIVER ############## */

#endif /* AVR_H_ */
```

6.2.5 AVR.c

```c
#include <stdio.h>
#include <stdlib.h>
#include <avr/interrupt.h>
#include <avr/io.h>
#include <avr/pgmspace.h>
#include <util/delay.h>

#include "AVR.h"

/* ======= INTERRUPT SERVICE ROUTINES ======= */
// Interrupt Service Routine for INT4
ISR(INT4_vect)
{
   // read interrupt address, also clears interrupt signal
   volatile uint8_t cmd = READ_RAM(RAM_INT_GET);

   switch (cmd)
   {
      // Copy LED data from DPRAM into RAM (sets correct byte order) and
clock out the data
      case CMD_LEDS_SEND:
      {
         // Amount of LEDS connected
         uint8_t n = READ_RAM(RAM_LEDS_AMOUNT);
         // Global LED dimmer settings
         uint8_t dim = READ_RAM(RAM_LEDS_DIM);
         // Make sure that n <= MAX_LEDS to prevent data corruption
         if (n > MAX_LEDS) n = MAX_LEDS;
         // used for DPRAM address offset from RAM_LEDS_START
         uint16_t offset = 0;
         for (uint16_t i = 0; i < n; i++)
         {
            LEDS[i].r = READ_RAM(RAM_LEDS_START + (offset ++)) & dim;
            LEDS[i].g = READ_RAM(RAM_LEDS_START + (offset ++)) & dim;
            LEDS[i].b = READ_RAM(RAM_LEDS_START + (offset ++)) & dim;
         }
         // Clock out data
         sendLEDS(n);
      }
      break;
      // Shortcut command to set LCD cursor position
      case CMD_LCD_POS:
      {
         sendLCDInstructionByte(READ_RAM(RAM_LCD_CMD) | 0b10000000);
      }
      break;
      // Send LCD an insrtuction byte
      case CMD_LCD_CMD:
      {
         sendLCDInstructionByte(READ_RAM(RAM_LCD_CMD));
      }
      break;
      // Shortcut for clear & print
      case CMD_LCD_CL_PR:
      {
         sendLCDInstructionByte(0x01);
         _delay_ms(10);
      }
      // no break!
      // Print char buffer (until max chars or 0x00)
      case CMD_LCD_CHAR:
      {
         for (uint8_t i = 0; i < MAX_LCD_CHARS; i++)
         {
            uint8_t c = READ_RAM(RAM_LCD_START + i);
            if (c == 0x00) break;
            sendLCDCharacterByte(c);
         }
      }
      break;
      case CMD_LCD_BL_ON: LCD_BACKLIGHT = 1; break;
      case CMD_LCD_BL_OFF: LCD_BACKLIGHT = 0; break;
   }
   /* Interrupt detection debug code */
   #if DEBUG
      char buff[10];
      sprintf(buff, "I:0x%02X", cmd);
      sendLCDBuffer(buff);
   #endif
   sei();
}

/* ================== DEBUG STUFF ================== */
/* HANDLE DEBUG KEYPRESS HERE */
void debugKeypress(uint8_t key)
{
   // buffer index pointer
   static uint8_t b = 0;
   // buffer (20 chars = 1 line)
   static char buffer[20];

   switch (key)
   {
      // SEND
      case '*':
      {
         sendLEDS(30);

         b = 0;
         buffer[b] = 0;
         sendLCDInstructionByte(0x01);
         _delay_ms(2);
         sprintf(buffer, "      0x%02X 0x%02X 0x%02X", LEDS[0].r,
LEDS[0].g, LEDS[0].b);
         sendLCDBuffer(buffer);
         // 1e pos on lcd
         sendLCDInstructionByte(0x80);
         break;
      }
      // BACKSPACE
      case '#':
      {
         if (b != 0) b--;
         buffer[b] = 0;

         sendLCDInstructionByte(0x01);
         _delay_ms(2);

         sendLCDBuffer(buffer);
         break;
      }
      // SET RED
      case 'A':
      {
         uint8_t nr = atoi(buffer);
         for (uint8_t i = 0; i < 30; i++)
         {
            LEDS[i].r = nr;
         }
         b = 0;
         buffer[b] = 0;
         sendLCDInstructionByte(0x01);
         _delay_ms(2);
```

```
            break;
         }
         // SET GREEN
         case 'B':
         {
            uint8_t nr = atoi(buffer);
            for (uint8_t i = 0; i < 30; i++)
            {
               LEDS[i].g = nr;
            }
            b = 0;
            buffer[b] = 0;
            sendLCDInstructionByte(0x01);
            _delay_ms(2);
            break;
         }
         // SET BLUE
         case 'C':
         {
            uint8_t nr = atoi(buffer);
            for (uint8_t i = 0; i < 30; i++)
            {
               LEDS[i].b = nr;
            }
            b = 0;
            buffer[b] = 0;
            sendLCDInstructionByte(0x01);
            _delay_ms(2);
            break;
         }
         case 'D':
         {
            sendLCDInstructionByte(0x01);
            for (uint8_t i = 0; i < MAX_LCD_CHARS; i++)
            {
               uint8_t c = READ_RAM(RAM_LCD_START + i);
               if (c == 0x00) break;
               sendLCDCharacterByte(c);
            }
         }
         break;
         // NUMBER
         default:
         {
            buffer[b++] = key;
            buffer[b] = 0;
            sendLCDCharacterByte(key);
            break;
         }
      }
   }

   /* ================== MAIN ================== */
   int main()
   {
      // set ports & interrupt registers
      inits();

      #if DEBUG
      // debounce variables
      uint8_t prevKey = 0x00;
      uint16_t downTime = 0;
      uint16_t upTime = 0;

      // debug program loop (aka keypad scanner)
      while (1)
      {
        // ROW loop
        for (uint8_t r = 0; r < 4; r++)
        {
            // all pins HIGH, the row we want to read LOW; bit 0-4 always high
because they are inputs (pull-up).
            KP_PORT = 0x0F | (0b11101111 << r);
            // Convert read port byte (inverted because pull-ups)

            uint8_t key = readMatrix(~KP_PIN);
            // no key pressed
            if (key == 0x00)
            {
                // if no key was pressed for 100+ ms, reset debounce.
                if (upTime++ > 100)
                {
                    // Makes sure the next keypress will register instantly
                    prevKey = 0x00;

                    downTime = 0;
                    upTime = 0;
                }
            }
            else // A key was pressed
            {
                // if the pressed key is different from the last one OR its
been pressed for 500+ ms, acknowledge as a legitimate press
                if (prevKey != key || downTime++ > 500)
                {
                    // Store key in DPRAM for SC12
                    WRITE_RAM(RAM_KP_LASTKEY, key);
                    // Send interrupt to SC12
                    WRITE_RAM(RAM_INT_SEND, SATUS_KP_PRESS);

                    debugKeypress(key);

                    // Store current key for debounce
                    prevKey = key;

                    downTime = 0;
                    upTime = 0;
                }
            }

            _delay_ms(1);
        }
    }
    #else
    while (1)
    {

    }
    #endif
}

/* =============== FUNCTIONS ============== */
void inline inits()
{
    // Write SRE to 1 enables the External Memory Interface
    MCUCR = 0x80;

    // Magic numbers
    WRITE_RAM(RAM_VERSION_1, 42);
    WRITE_RAM(RAM_VERSION_2, 0x42);

    // LCD Port Setup
    LCD_DDR = 0xFF;

```

```c
   // Keypad Port Setup (bit 0-3 = in; bit 4-7 = out)
   KP_DDR = 0xF0;

   // LED port all output
   LEDS_DDR = 0xEF;
   LEDS_PORT = (uint8_t)~0xEF;

   // Enable falling edge interrupt INT4
   EICRB = 0x02;
   EIMSK = 0x10;

   // LCD init
   _delay_ms(100);

   // Set 4 bit mode
   sendLCDNible(0x02, 0);
   // 2-line mode, display on
   sendLCDInstructionByte(0x0C);
   _delay_ms(100);

   // Display ON/OFF Control
   sendLCDInstructionByte(0x0F);
   // Clear & home
   sendLCDInstructionByte(0x01);
   _delay_ms(20);
   // Entry mode Increment & Entire shift off
   sendLCDInstructionByte(0x06);

   // Clear any open interrupts.
   volatile uint8_t i = READ_RAM(RAM_INT_GET);
   // Global interrupts ON
   sei();
}

uint8_t inline readMatrix(uint8_t matrix)
{
   switch (matrix)
   {
      default: return 0x00;

      case 0b00010001: return '1'; // 0x11
      case 0b00010010: return '4'; // 0x12
      case 0b00010100: return '7'; // 0x13
      case 0b00011000: return '*'; // 0x18

      case 0b00100001: return '2'; // 0x21
      case 0b00100010: return '5'; // 0x22
      case 0b00100100: return '8'; // 0x24
      case 0b00101000: return '0'; // 0x28

      case 0b01000001: return '3'; // 0x41
      case 0b01000010: return '6'; // 0x42
      case 0b01000100: return '9'; // 0x44
      case 0b01001000: return '#'; // 0x48

      case 0b10000001: return 'A'; // 0x81
      case 0b10000010: return 'B'; // 0x82
      case 0b10000100: return 'C'; // 0x84
      case 0b10001000: return 'D'; // 0x88
   }
}

/* ##############  START SECTION WS2812 DRIVER ##############
 * Original Source:    https://github.com/cpldcpu/light_ws2812/
 * Original Author:    Tim (cpldcpu@gmail.com)
 * Original License:   GNU GPL V2
(https://github.com/cpldcpu/light_ws2812/blob/master/License.txt)
```

```
 *     This license still applies to everything between the "WS2812 DRIVER"
section lines.
 *
 * Modifications by Dries007:
 * -  Changed configuration
 * -  Merged library into single set of source and header files
 */
void inline sendLEDS(uint16_t leds)
{
   // 3 colors!
   uint16_t datlen = leds + leds + leds;
   // Type cast
   uint8_t * data = (uint8_t *) LEDS;

   // Save interrupt status
   uint8_t sreg_prev = SREG;
   // We can't be interrupted!
   cli();

   uint8_t maskhi = _BV(LEDS_PIN);
   // Low mask
   uint8_t masklo = ~maskhi&LEDS_PORT;
   // High mask
   maskhi |= LEDS_PORT;

   // used in ASM
   uint8_t curbyte, ctr;
   while (datlen--)
   {
      curbyte = *data ++; // Grab byte

      asm volatile(
      "       ldi   %0,8  \n\t" // Write 8 (00001000) to Loop counter (%0)
      "loop%=:            \n\t" // Loop entry point (%= is a unique number
on each asm statement)
      "       out   %2,%3 \n\t" // Write High mask (%3) to LED_PORT (%2)
      #if (w1_nops&1)   // w1 nops for timing
      w_nop1
      #endif
      #if (w1_nops&2)
      w_nop2
      #endif
      #if (w1_nops&4)
      w_nop4
      #endif
      #if (w1_nops&8)
      w_nop8
      #endif
      #if (w1_nops&16)
      w_nop16
      #endif
      "       sbrs  %1,7  \n\t" // Skip next instruction if bit 7 of Data
(%1) is set
      "       out   %2,%4 \n\t" // Write Low mask (%4) to LED_PORT (%2)
      "       lsl   %1    \n\t" // Shift Data (%1) left
      #if (w2_nops&1) // w2 nops for timing
      w_nop1
      #endif
      #if (w2_nops&2)
      w_nop2
      #endif
      #if (w2_nops&4)
      w_nop4
      #endif
      #if (w2_nops&8)
      w_nop8
      #endif
```

```
       #if (w2_nops&16)
       w_nop16
       #endif
       "       out   %2,%4 \n\t" // Write Low mask (%4) to LED_PORT (%2)
       #if (w3_nops&1) // w3 nops for timing
       w_nop1
       #endif
       #if (w3_nops&2)
       w_nop2
       #endif
       #if (w3_nops&4)
       w_nop4
       #endif
       #if (w3_nops&8)
       w_nop8
       #endif
       #if (w3_nops&16)
       w_nop16
       #endif
       "       dec   %0    \n\t" // Decrement Loop counter (%0) (Also sets Z
if 0x00)
       "       brne  loop%=\n\t" // Jump to Loop entry point if Z is set.
       // %0 = 8 bit loop counter
       :  "=&d" (ctr)
       :  "r" (curbyte), "I" (_SFR_IO_ADDR(LEDS_PORT)), "r" (maskhi), "r"
(masklo)
       // %s1 = Data      %2 = LEDS_PORT                %3 = high mask  %4 =
low mask
       );
   }
   SREG = sreg_prev; // Restore interrupt status
   _delay_us(50); // Reset delay
}
/* ##############  END SECTION WS2812 DRIVER ##############  */

void sendLCDNible(volatile uint8_t data, uint8_t rs)
{
   // Mask out fist 4 bits
   data &= 0b00001111;
   // Mask in LCD_BACKLIGHT if required (pin 7)s
   if (LCD_BACKLIGHT) data |= 0b10000000;
   // Mask in register select
   if (rs) data |= 0b01000000;
   // Bit 4 => 1, its the interrput pin, its on pull-up!
   data |= 0b00010000;
   // Set Data
   LCD_PORT = data;
   // Small delay, data needs to be valid BEFORE enable
   _delay_us(800);
   // Toggle enable
   LCD_PORT |= 0b00100000;
   // Larger delay, LCD needs time to process
   _delay_us(800);
}

void sendLCDInstructionByte(uint8_t data)
{
   // rs = 0 -> instruction
   sendLCDNible(data >> 4, 0);
   sendLCDNible(data, 0);
}

void sendLCDCharacterByte(char data)
{
   // rs = 1 -> data
   sendLCDNible(data >> 4, 1);
   sendLCDNible(data, 1);
```

```
}

void sendLCDBuffer(char * buffer)
{
   // max chars
   for (uint8_t i = 0; i < MAX_LCD_CHARS; i++)
   {
      // End on 0x00
      if (buffer[i] == 0x00) break;
      sendLCDCharacterByte(buffer[i]);
   }
}
```